

An Interim Report for NASA Grant NAG-5-1843 for

February, 1995 to February, 1996

"Experimental Studies of the Far-Infrared Spectra of Cosmic-Type Ices"

Submitted to:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

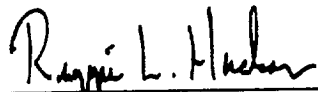
Attention: Ms. Gloria R. Blanchard
Grants Officer, Code 286.1

Submitted by:

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March 2, 1996

Respectfully Submitted,



Reggie L. Hudson

The purpose of the grant was to support work done in collaboration with Dr. Marla H. Moore of the Goddard Space Flight Center. The funds were used primarily to cover a trip to and from Goddard during the summer of 1995 and to cover travel for an astrochemistry symposium in Charlottesville, Virginia.

Research

The major accomplishment during the grant period was experimental research during the summer of 1995. An experimental apparatus was set up for studies of far-infrared properties of frozen H₂O and other ices. The motivation for this work was that the PI and Dr. Moore of NASA are collaborators on an upcoming project with European scientists. The data generated under the present grant will be combined with observations made with the ESA's ISO spacecraft, launched in November, 1995. The purpose of the collaboration is to determine the characteristics of ices in selected astronomical objects.

Under the present grant, a set of far-infrared spectra were recorded under a variety of conditions of temperature, solid form, and thermal history for the samples. The measurements were made by passage of an infrared beam through ice samples, and so supplement work made previously on reflected infrared spectra. Copies of the data now reside at Eckerd College, at Goddard, and at Catania in Italy.

Travel

The major travel cost was to attend an astrochemistry meeting at the University of Virginia in November, 1995. The PI served as the chair of one session and his collaborator gave a paper at another. The work presented at the meeting covered a broad range of astrochemical topics (e.g., dust, ices, interstellar molecules, circumstellar matter, comets) related to this grant.

Related Work

Three minor projects were undertaken during the period of this grant. The first was a workshop for teachers at the Astronomical Society of the Pacific's meeting in June, 1995 at College Park, Maryland. This work was done in conjunction with NASA scientist Dr. Marla H. Moore. The second minor project was the PI's service as a reviewer for proceedings of a comet workshop in France. The third activity was that the PI served as a reviewer for a scientific proposal from NASA headquarters (Planetary Sciences).

Remaining Funds

The remaining funds, about \$ 2000, will be used to continue research on cosmic-type ices during 1996. This will include some salary, travel, and, perhaps, some minor software and equipment costs.

Appendix

A list of some of the data files generated during the period of this grant is attached, as are some sample spectra. Additional information and the actual data are available on request.

FAR-IR EXPERIMENTS WITH WATER DURING JULY-AUGUST, 1995

FOR ISO USE

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The spectra were recorded in transmission mode (no reflection measurements) with a silicon substrate. The spectral range was approximately $100 - 500 \text{ cm}^{-1}$ ($20 - 100 \text{ }\mu\text{m}$) with a spectral resolution of 4 cm^{-1} . The number of scans was 700 in cases where the signal-to-noise ratio was low but 60 otherwise. The data were converted to ascii (wavenumber, absorbance) values with absorbance, A, defined as $\log(I_0/I)$, and "log" is to base 10. The data points are spaced at intervals of about 0.24 cm^{-1} .

Data Set #1 (deposition at 14 K and warming)

The main source of the data used is experiment FIRH2O13. The sole exception is that the 160 K spectrum in data set #1 was taken from experiment FIRH2O10 and scaled to match the FIRH2O13 data.

Water was deposited for 39 minutes at 14 K. Far-IR absorbance spectra were recorded at 14, 40, 80, 100, 120, 140, and 160 K. Spectral baselines were adjusted to give an absorbance of 0 at 500, 400, 350, and 100 cm^{-1} . The spectrum at 14 K had a maximum absorbance of 0.37 at 218 cm^{-1} . Using the optical constants of Hudgins et al. (*Ap. J. Suppl. Ser.*, 1993, 86, 713), this absorbance gives an ice thickness of $(10000 \text{ }\mu\text{m} / \text{cm}) \times (2.303 \times 0.37) / 1189 \text{ cm}^{-1} = 7.2 \text{ }\mu\text{m}$. Thus the deposition rate was $7.2 \text{ }\mu\text{m} \times 60 / 39 = 11 \text{ }\mu\text{m/hr}$. The spectrum at 160 K involved 60 scans while spectra for the other six temperatures involved 700 each. The specific data files are as follows:

T	Experiment	Original File Name	File Name After Baseline Adjusted	Name of Back- ground File
14 K	FIRH2O13	spctra07	spctrc07	FIRH2O13\#02
40 K	FIRH2O13	spctrx08	spctcx08	FIR-H2O8\#25
80 K	FIRH2O13	spctrx09	spctcx09	FIRH2O13\#13
100 K	FIRH2O13	spctra10	spctrc10	FIRH2O12\#18
120 K	FIRH2O13	spctra11	spctrc11	FIRH2O12\#18
140 K	FIRH2O13	spctra12	spctrc12	FIRH2O12\#18
160 K	FIRH2O10	spctrx18	spctcx18	FIRH2O10\#21

Data Set #2 (deposition at 160 K and cooling)

The source of the data used is experiment FIR-H2O8. Water was deposited for 60 minutes at 160 K. Far-IR absorbance spectra were recorded at 160, 140, 120, 100, 80, 40, and 14 K. Spectral baselines were adjusted to give an absorbance of 0 at 500, 400, 350, and 100 cm^{-1} . The spectrum at 160 K had a maximum absorbance of 0.75 at 225 cm^{-1} . Using the optical constants of Bertie et al. (*J. Chem. Phys.*, 1969, 50, 4501), or comparing with the measurements of Smith et al. (*MNRAS*, 1994, 271, 481), a thickness of about 5 μm was estimated for the ice. Thus the deposition rate was 5 $\mu\text{m/hr}$. The spectrum at 160 K involved 700 scans while spectra for the other six temperatures involved 60 each. The specific data files are as follows:

T	Experiment	Original File Name	File Name After Baseline Adjusted	Name of Background File
160 K	FIR-H2O8	spctra13	spctrc13	FIR-H2O8\#08
140 K	FIR-H2O8	spctrx20	spctcx20	FIR-H2O8\#26
120 K	FIR-H2O8	spctrx19	spctcx19	FIR-H2O8\#26
100 K	FIR-H2O8	spctrx17	spctcx17	FIR-H2O8\#26
80 K	FIR-H2O8	spctrx16	spctcx16	FIR-H2O8\#26
40 K	FIR-H2O8	spctrx15	spctcx15	FIR-H2O8\#25
14 K	FIR-H2O8	spctrx14	spctcx14	FIR-H2O8\#23

Data Set #3 (depositions at 14 K < T < 160 K)

Water was deposited at 140, 120, 100, 80, and 40 K, and far-IR absorbance spectra were recorded at each temperature. The sources of the data used are experiments FIR-H2O7 (140 and 120 K), FIR-H2O6 (100 K), FIR-H2O5 (80 K), and FIRH2O11 (40 K). Spectral baselines were adjusted to give an absorbance of 0 at 500, 400, 350, and 100 cm^{-1} . The maximum absorbance of each spectrum was compared to the measurements of Smith et al. (*MNRAS*, 1994, 271, 481) to estimate ice thicknesses and, in turn, the deposition rates. These are summarized below:

T	Deposition Time	Maximum Absorbance	Estimated Thickness	Deposition Rate
140 K	100 min	0.96	6.9 μm	4.1 $\mu\text{m/hr}$
120 K	75 min	0.71	5.1 μm	4.0 $\mu\text{m/hr}$
100 K	115 min	0.47	7.6 μm	4.0 $\mu\text{m/hr}$
80 K	75 min	0.46	7.4 μm	6.0 $\mu\text{m/hr}$
40 K	36 min	0.35	5.6 μm	9.3 $\mu\text{m/hr}$

The specific data files used in this set are as follows:

T	Experiment	Original File Name	File Name After Baseline Adjusted	Name of Back- ground File
140 K	FIR-H2O7	spctra37	spctrc37	FIR-H2O7\#31
120 K	FIR-H2O7	spctrx13	spctcx13	FIR-H2O7\#31
100 K	FIR-H2O6	spctra12	spctrc12	FIR-H2O6\#08
80 K	FIR-H2O5	spctra25	spctrc25	FIR-H2O5\#21
40 K	FIRH2O11	spctra04	spctrc04	FIRH2O11\#02

The following two are useful for comparison with the above five. These two are from data sets #1 and #2.

T	Experiment	Original File Name	File Name After Baseline Adjusted	Name of Back- ground File
160 K	FIR-H2O8	spctra13	spctrc13	FIR-H2O8\#08
14 K	FIRH2O13	spctra07	spctrc07	FIRH2O13\#02

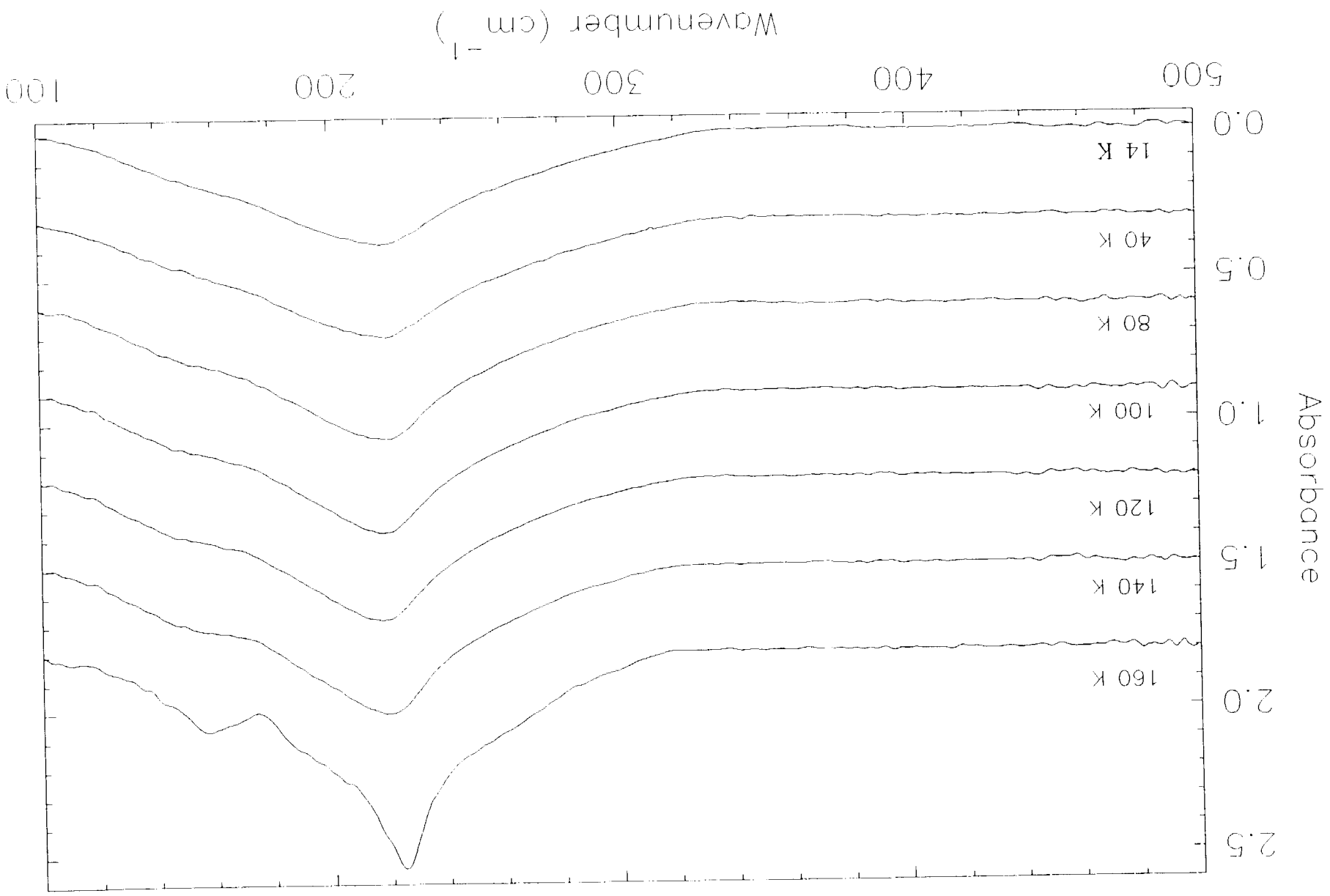
FAR-IR DATA FILES

set1-014.txt: deposited at 14 K
 set1-040.txt: deposited at 14 K and warmed to 40 K
 set1-080.txt: deposited at 14 K and warmed to 80 K
 set1-100.txt: deposited at 14 K and warmed to 100 K
 set1-120.txt: deposited at 14 K and warmed to 120 K
 set1-140.txt: deposited at 14 K and warmed to 140 K
 set1-160.txt: deposited at 14 K and warmed to 160 K

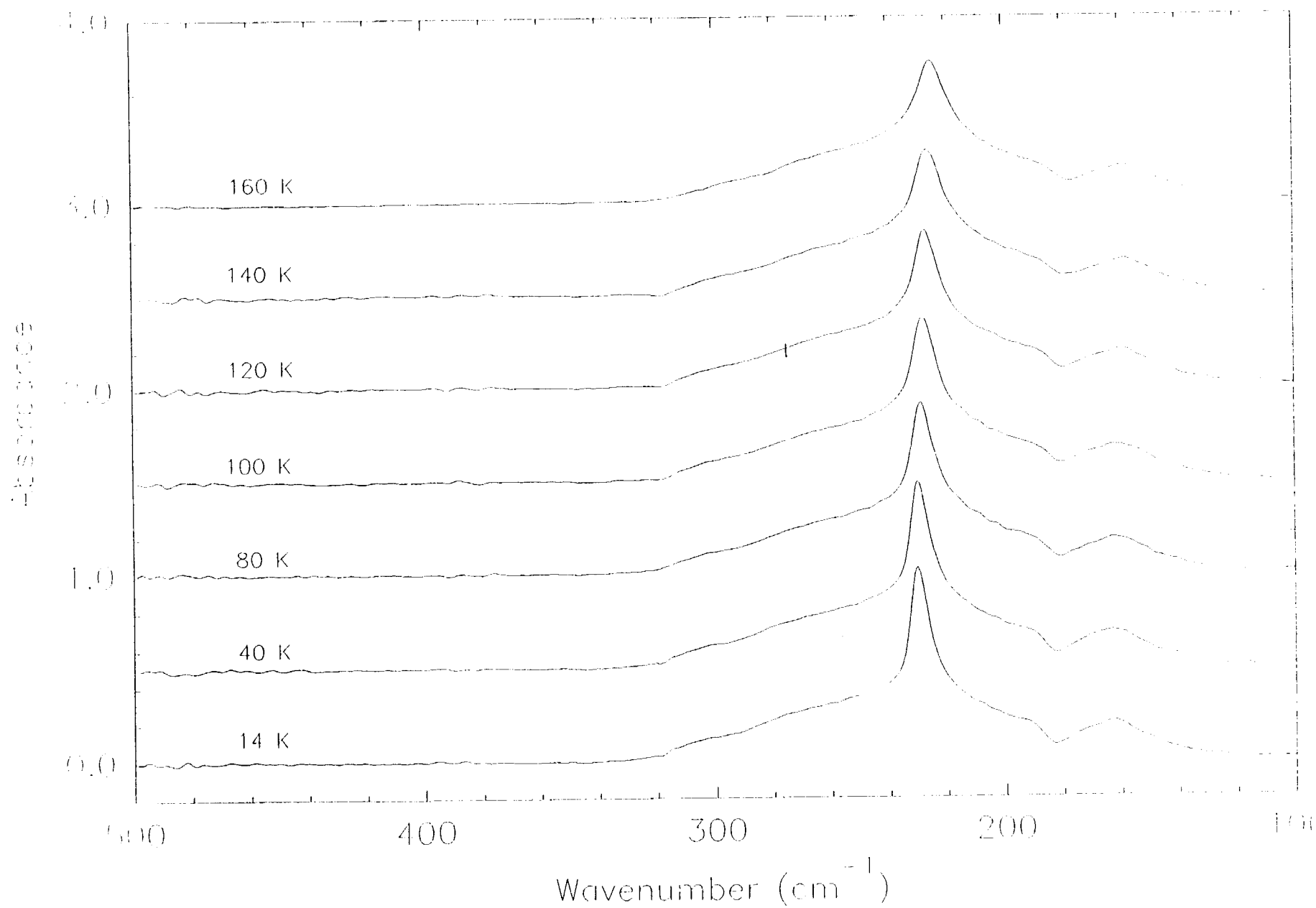
set2-160.txt: deposited at 160 K
 set2-140.txt: deposited at 160 K and cooled to 140 K
 set2-120.txt: deposited at 160 K and cooled to 120 K
 set2-100.txt: deposited at 160 K and cooled to 100 K
 set2-080.txt: deposited at 160 K and cooled to 80 K
 set2-040.txt: deposited at 160 K and cooled to 40 K
 set2-014.txt: deposited at 160 K and cooled to 14 K

set3-140.txt: deposited at 140 K
 set3-120.txt: deposited at 120 K
 set3-100.txt: deposited at 100 K
 set3-080.txt: deposited at 80 K
 set3-040.txt: deposited at 40 K

FAR-IR SPECTRA OF H₂O DEPOSITED AT 14 K AND WARMED



FAR-IR SPECTRA OF H₂O ICE MADE AT 160 K THEN COOLED



FAR-IR SPECTRA OF H₂O AT DIFFERENT DEPOSITION TEMPERATURES

